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MULTICHANNEL ORTHOGONAL FREQUENCY DIVISION
MULTIPLEXED RECEIVERS WITH ANTENNA SELECTION AND
MAXIMUM-RATIO COMBINING AND ASSOCIATED METHODS

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5

Technical Field

Embodiments of the present invention pertain to wireless electronic communications, and in some embodiments, the present invention pertains to orthogonal frequency division multiplexed (OFDM) communications.

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Background

Many modern digital communication systems, including wireless local-area networks (WLANs), are using symbol-modulated orthogonal subcarriers as a modulation scheme to help signals survive in environments having multipath reflections and/or strong interference. Orthogonal frequency-division multiplexing (OFDM) is an example of a multi-carrier transmission technique that uses symbol-modulated orthogonal subcarriers to transmit information within an available spectrum.

20 One problem with many WLAN receivers, including OFDM receivers, is that they are limited by their hardware configuration as to the particular channels they can receive as well as the bandwidth of those channels. This leaves such receivers inflexible as to tradeoffs between throughput and range. WLAN receivers, including OFDM receivers, should be able to receive both legacy
25 channels, such as channels in accordance with Institute of Electrical and Electronics Engineers (IEEE) standard 802.11 (a), as well as wideband channels for high-throughput operations. These requirements make it difficult to make tradeoffs between throughput and range, especially when operating in high-throughput and/or wideband modes. Thus, there are general needs for
30 transceivers, including receivers, and methods of communicating OFDM signals that provide flexibility between throughput and range in WLANs.

Brief Description of the Drawings

The appended claims are directed to some of the various embodiments of the present invention. However, the detailed description presents a more
5 complete understanding of embodiments of the present invention when considered in connection with the figures, wherein like reference numbers refer to similar items throughout the figures and:

FIGs. 1A & 1B are block diagrams of a receiver in accordance with some embodiments of the present invention;

10 FIGs. 2A & 2B are block diagrams of a receiver in accordance with some embodiments of the present invention;

FIGs. 3A & 3B are block diagrams of a receiver in accordance with some embodiments of the present invention; and

15 FIG. 4 is a flow chart of an OFDM signal reception procedure in accordance with some embodiments of the present invention.

Detailed Description

The following description and the drawings illustrate specific
20 embodiments of the invention sufficiently to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Examples merely typify possible variations. Individual components and functions are optional unless explicitly required, and the sequence of operations may vary. Portions and features of some
25 embodiments may be included in or substituted for those of others. The scope of embodiments of the invention encompasses the full ambit of the claims and all available equivalents of those claims. Such embodiments of the invention may be referred to, individually or collectively, herein by the term “invention” merely for convenience and without intending to voluntarily limit the scope of this
30 application to any single invention or inventive concept if more than one is in fact disclosed.

FIGs. 1A & 1B, FIGs. 2A & 2B, and FIGs. 3A & 3B illustrate some embodiments of various receiver configurations in accordance with the

invention. Receiver configurations 100 (FIGs. 1A & 1B), 200 (FIGs. 2A & 2B) and 300 (FIGs. 3A & 3B) may be part of a wireless communication device, and they may receive orthogonal frequency division multiplexed (e.g., OFDM) communication signals. In some embodiments, the receivers may receive an
5 OFDM packet comprising several OFDM symbols over a wideband communication channel. The wideband channel may comprise one or more subchannels. The subchannels may be frequency-division multiplexed (i.e., separated in frequency) and may be within a predetermined frequency spectrum. The subchannels may comprise a plurality of orthogonal subcarriers. In some
10 embodiments, the orthogonal subcarriers of a subchannel may be closely spaced OFDM subcarriers. To achieve orthogonality between closely spaced subcarriers, in these embodiments, the subcarriers of a particular subchannel may have a null at substantially a center frequency of the other subcarriers of that subchannel.

Receiver configurations 100 (FIGs. 1A & 1B), 200 (FIGs. 2A & 2B) and
15 300 (FIGs. 3A & 3B) may be reconfigurable multichannel receivers that may selectively operate in increased throughput modes and/or increased range modes. In some embodiments, receiver configuration 100 (FIGs. 1A & 1B) may select two or more antennas from a plurality of spatially diverse antennas to receive more than one subchannel of a wideband OFDM channel. Maximum-ratio
20 combining may be performed on corresponding symbol-modulated subcarriers from the two or more antennas, and a single OFDM symbol may be determined from contributions from the subchannels received by the two or more antennas. In other embodiments, receiver configuration 200 (FIGs. 2A & 2B) may receive more than one subchannel of a wideband OFDM channel with a single antenna
25 selected from a plurality of spatially diverse antennas. In some other embodiments, receiver configuration 300 (FIGs. 3A & 3B) may receive a single subchannel with more than one of a plurality of spatially diverse antennas and maximum-ratio combining may be performed on corresponding symbol-modulated subcarriers received by the different antennas.

30 In accordance with some embodiments, receiver configurations 100 (FIGs. 1A & 1B), 200 (FIGs. 2A & 2B) and 300 (FIGs. 3A & 3B) may receive symbol-modulated subcarriers in accordance with individual subcarrier modulation assignments. This may be referred to as adaptive bit loading (ABL).

Accordingly, one or more bits may be represented by a symbol modulated on a subcarrier. The modulation assignments for the individual subchannels may be based on the channel characteristics or channel conditions for that subcarrier, although the scope of the invention is not limited in this respect. In some
5 embodiments, the subcarrier modulation assignments may range from zero bits per symbol to up to ten or more bits per symbol. In terms of modulation levels, the subcarrier modulation assignments may comprise binary phase shift keying (BPSK), which communicates one bit per symbol, quadrature phase shift keying (QPSK), which communicates two bits per symbol, 8PSK, which communicates
10 three bits per symbol, 16-quadrature amplitude modulation (16-QAM), which communicates four bits per symbol, 32-QAM, which communicates five bits per symbol, 64-QAM, which communicates six bits per symbol, 128-QAM, which communicates seven bits per symbol, and 256-QAM, which communicates eight bits per symbol. Modulation orders with higher data communication rates per
15 subcarrier may also be used.

 An OFDM symbol may be viewed as the combination of the symbols modulated on the individual subcarriers. Because of the variable number of bits per symbol-modulated subcarrier and the variable number of subchannels that may comprise a wideband channel, the number of bits per OFDM symbol
20 received by the receivers may vary greatly. For example, in some embodiments, a receiver may receive over a wideband channel that may comprise up to four or more subchannels having bandwidths of approximately 20 MHz, and each of the subchannels may have up to 48 or more orthogonal data subcarriers having a spacing therebetween of approximately 312.5 kHz. In other embodiments, a
25 receiver may receive an OFDM symbol over a single subchannel.

 In some embodiments, the frequency spectrums for a wideband channel may comprise subchannels in either a 5 GHz frequency spectrum or a 2.4 GHz frequency spectrum. In these embodiments, the 5 GHz frequency spectrum may include frequencies ranging from approximately 4.9 to 5.9 GHz, and the 2.4 GHz
30 spectrum may include frequencies ranging from approximately 2.3 to 2.5 GHz, although the scope of the invention is not limited in this respect, as other frequency spectrums are also equally suitable.

5 In some embodiments, receiver configurations 100 (FIGs. 1A & 1B), 200
(FIGs. 2A & 2B) and 300 (FIGs. 3A & 3B) may be part of a personal digital
assistant (PDA), a laptop or portable computer with wireless communication
capability, a web tablet, a wireless telephone, a wireless headset, a pager, an
instant messaging device, a digital camera, an access point or other device that
may receive and/or transmit information wirelessly. In some embodiments, the
receivers may receive radio-frequency communications in accordance with
specific communication standards, such as the Institute of Electrical and
Electronics Engineers (IEEE) standards including the IEEE 802.11(a), 802.11(b),
10 802.11(g/h) and/or 802.16 standards for wireless local area network
communications, although the receivers may also be suitable to receive
communications in accordance with other techniques including the Digital Video
Broadcasting Terrestrial (DVB-T) broadcasting standard, and the High
performance radio Local Area Network (HiperLAN) standard.

15 In some embodiments, the receivers may use up to four spatially diverse
antennas to exploit up to four 20 MHz channels. In some embodiments, a 20
MHz channel may be referred to as a single subchannel of a wideband channel.

In accordance with some embodiments of receiver configuration 100
(FIGs. 1A & 1B), two 20 MHz subchannels may be used to support wideband
20 channel operation of 40 MHz bandwidth with adaptive maximum-ratio
combining on each subcarrier involving two active antennas. In some of these
embodiments, receiver configuration 100 may simultaneously implement an
antenna selection technique that chooses a pair of active antennas with the best
receiving conditions from four antennas. These embodiments may provide a
25 throughput of up to 108 Mbps with mid-range operation capabilities, although
the scope of the present invention is not limited in this respect. In some
embodiments, receiver configuration 100 may be part of a transceiver that may
choose the two least loaded subchannels of four subchannels for data
transmission to help reduce collisions.

30 In accordance with some embodiments of receiver configuration 200
(FIGs. 2A & 2B), four 20 MHz subchannels may be used to support wideband
channel operations of 80 MHz bandwidth with adaptive antenna selection that
may choose one antenna with the best receiving conditions of four antennas for

transmitting and/or receiving. These embodiments may provide a throughput of up to 216 Mbps with a possible reduction in range, although the scope of the present invention is not limited in this respect.

5 In accordance with some embodiments of receiver configuration 200 (FIGs. 2A & 2B), three 20 MHz subchannels may be used to support wideband channel operation of 60 MHz bandwidth with adaptive antenna selection that may choose one antenna with the best receiving conditions of four for transmitting and/or receiving. These embodiments may provide a throughput up to 162 Mbps with an improved range, although the scope of the present invention
10 is not limited in this respect.

In accordance with some embodiments of receiver configuration 300 (FIGs. 3A & 3B), one subchannel may be received with four antennas with adaptive maximum-ratio combining on each subcarrier. In these embodiments, receiver configuration 300 may support transceiver configurations with possibly
15 significantly improved range capabilities and throughput of up to 54 Mbps, although the scope of the present invention is not limited in this respect. In some embodiments, receiver configuration 300 may be part of a transceiver that may choose a least loaded subchannel of four band subchannels for data transmission to help reducing collisions.

20 Although receiver configurations 100 (FIGs. 1A & 1B), 200 (FIGs. 2A & 2B) and 300 (FIGs. 3A & 3B) are illustrated separately, in some embodiments, the present invention also provides a single reconfigurable receiver that may operate in accordance with the functionality of receiver configurations 100 (FIGs. 1A & 1B), 200 (FIGs. 2A & 2B) and 300 (FIGs. 3A & 3B). In addition,
25 embodiments of the present invention also include transceivers that comprise transmitter circuitry, as well as receiver circuitry, to transmit communication signals that may be received by receivers in accordance with receiver configurations 100 (FIGs. 1A & 1B), 200 (FIGs. 2A & 2B) and/or 300 (FIGs. 3A & 3B).

30 In referring to FIGs. 1A & 1B, receiver configuration 100 includes antenna selection (AS) circuitry 104 to select more than one antenna of a plurality of spatially diverse antennas 102a-d to receive an orthogonal frequency division multiplexed symbol over a wideband channel. The wideband channel

may comprise more than one of a plurality of frequency-separated subchannels. Receiver configuration 100 may also include combining circuitry 124 to combine corresponding frequency domain symbol-modulated subcarriers 123 from the selected antennas to generate combined symbol-modulated subcarriers 125 and
5 127 for each subchannel of the wideband channel.

In some embodiments, antenna selection circuitry 104 may select a first antenna of the plurality of antennas 102a-d to receive two subchannels of a wideband channel, and the antenna selection circuitry 104 may also select a second antenna of the plurality of antennas 102a-d to further receive the two
10 subchannels of the wideband channel. In some embodiments, antenna selection circuitry 104 may select two of antennas to receive two subchannels simultaneously. In some embodiments, antenna selection circuitry 104 may select the first and the second antennas based on a signal-to-noise ratio (SNR) of signals in the wideband channel. In some embodiments, antenna selection
15 circuitry 104 may select the first and the second antennas based on an average SNR of signals in the wideband channel. In some embodiments, antenna selection circuitry may select the two antennas with the best average SNR for both subchannels.

Receiver configuration 100 may utilize low-noise amplifiers (LNAs)
20 106a-b for each selected antenna to amplify RF signals of more than one subchannel, and downconversion circuitry 108 to individually downconvert RF signals for each subchannel that is received through each antenna. For example, when two subchannels are received through two of antennas 102a-d, receiver configuration 100 may include first downconversion circuitry 108a to
25 downconvert RF signals of the first subchannel received by the first antenna, second downconversion circuitry 108b to downconvert RF signals of the second subchannel received by the first antenna, third downconversion circuitry 108c to downconvert RF signals of the first subchannel received by the second antenna, and fourth downconversion circuitry 108d to downconvert RF signals of the
30 second subchannel received by the second antenna. In embodiments, first low-noise amplifier 106a may amplify the RF signals from the first antenna, and second low-noise amplifier 106b may amplify the RF signals from the second antenna, although the scope of the invention is not limited in this respect. As

illustrated, downconversion circuitry 108 may provide both in-phase (I-channel) components and quadrature-phase (Q-channel) components, although the scope of the invention is not limited in this respect.

In some embodiments, heterodyne frequency generating circuitry 110
5 may selectively generate one or more heterodyne frequencies to convert RF signals of the particular subchannels to baseband. The particular heterodyne frequency may depend on the particular subchannel. In some embodiments when two subchannels are received through two of antennas 102a-d, heterodyne frequency generating circuitry 110 may provide a first heterodyne frequency to
10 first and third downconversion circuitry 108a and 108c to downconvert a first subchannel to baseband, and heterodyne frequency generating circuitry 110 may provide a second heterodyne frequency to second and fourth downconversion circuitry 108b and 108d to downconvert a second subchannel to baseband.

In some embodiments, heterodyne frequency generating circuitry 110
15 may comprise a fixed frequency voltage controlled oscillator (VCO) to generate a constant reference frequency, and a direct digital synthesizer (DDS) to generate a selected one of a plurality of stepped frequencies. Heterodyne frequency generating circuitry 110 may also comprise a frequency combiner to combine the reference frequency and the selected one of the stepped frequencies to generate
20 the proper heterodyne frequency for each downconversion circuitry 108. In some embodiments, heterodyne frequency generating circuitry 110 may further comprise a phase-locked loop (PLL) synthesizer and a frequency divider to operate with the VCO to generate the heterodyne frequencies. Other configurations for selectively generating heterodyne frequencies may also be
25 suitable for use with embodiments of the present invention.

Receiver configuration 100 may also include low-pass filters (LPFs)
112a-d to filter and/or accumulate signal information received from associated downconversion circuitry 108 and analog-to-digital conversion (ADC) circuitry
114a-d to generate digital signals 115 for each subchannel received through each
30 antenna. In some embodiments, digital signals 115 may comprise a serial symbol stream for each subchannel received through each antenna. Digital signals 115 provided by portion 118 of receiver configuration 100 may be processed in digital signal processing circuitry 116 to demodulate an OFDM symbol. In some

embodiments, analog-to-digital conversion circuitry 114a-d may provide a serial symbol stream for both the I and Q channel components. In the embodiments illustrated in FIGs. 1A & 1B, four single channel pipelines (SCPs) are shown. A single channel pipeline is shown for each of two subchannels that are received by each of the two antennas; however the scope of the invention is not limited in this respect.

In some embodiments, receiver configuration 100 may also include circuitry 120a-d to remove a cyclic extension and/or guard interval (GI) from the serial symbol streams provided by analog-to-digital conversion circuitry 114a-d, although the scope of the present invention is not limited in this respect. Serial symbol streams 121 may be converted to a parallel form for processing by fast Fourier transform (FFT) circuitry 122a-d. FFT circuitry 122a-d may perform a fast Fourier transform on the parallel groups of time-domain samples to generate frequency domain symbol-modulated subcarriers 123. In some embodiments, FFT circuitry 122a-d may also generate a channel estimate for each subcarrier of the received subchannels based on receipt of training symbols, although the scope of the present invention is not limited in this respect.

Combining circuitry 124 may combine corresponding frequency domain symbol-modulated subcarriers of the same subchannel (received by different antennas) to generate combined symbol-modulated subcarriers 125 and 127. In some embodiments, combined symbol-modulated subcarriers 125 may be associated with a first subchannel, and combined symbol-modulated subcarriers 127 may be associated with a second subchannel, although the scope of the invention is not limited in this respect.

In some embodiments, combining circuitry 124 comprises maximum-ratio combining (MRC) circuitry having complex (i.e., I and Q) weighters 130a-d to weight the frequency domain symbol-modulated subcarriers prior to proportionally combining the corresponding frequency domain symbol-modulated subcarriers substantially proportional to their signal strength in combiners 132. In these embodiments, weighters 130a-d may, in addition to weighting, correct, adjust and/or phase-rotate a frequency domain symbol-modulated subcarrier to allow coherent signal combining in combiners 132.

Receiver configuration 100 may also include equalizer circuitry 126a-b to perform a channel equalization on symbol-modulated subcarriers 125 and 127, which may be received in parallel for each subcarrier. The channel equalization may be based on channel estimates provided by the FFT circuitry. In some
5 embodiments, equalizer circuitry 126a-b may perform separate channel equalizations on the combined symbol-modulated subcarriers of an associated subchannel provided by the combining circuitry, although the scope of the present invention is not limited in this respect.

 In some embodiments, equalizer circuitry 126a-b may perform a channel
10 equalization for further demapping the combined symbol-modulated subcarriers of each subchannel to generate parallel groups of bits from the subcarriers. Additional processing circuitry 128 may generate a single decoded bit stream, which may represent the orthogonal frequency division multiplexed symbol, from the parallel groups of bits of more than one subchannel. In some
15 embodiments, additional processing circuitry 128 may include demapping circuitry, deinterleaving circuitry and/or decoding circuitry to generate the demodulated OFDM symbol. In some embodiments, subcarrier demappers may demap the subcarriers of each subchannel in accordance with individual subcarrier modulation assignments particular to the subchannel to generate the
20 parallel groups of bits. In some embodiments, a parallel-to-serial conversion may be performed prior to deinterleaving and/or decoding, and decoded bit stream 129 may be generated.

 In some embodiments, the channel estimates generated by FFT circuitry 122a-d may comprise a channel response across the channel bandwidth. The
25 channel estimates may be measured based on a channel sounding preamble and may include a channel estimate for each subcarrier frequency. In some embodiments, FFT circuitry 122a-d may perform an FFT on known training symbols (e.g., the long training symbols) so that a channel estimation may be determined for each subchannel. In some embodiments, equalizer circuitry 126a-
30 b may perform a channel equalization in the frequency domain with complex values that represent the channel estimate so that magnitudes of the frequency domain symbol-modulated subcarriers may be normalized and the phases of the

frequency domain symbol-modulated subcarriers may be aligned to a zero origin to allow for further processing by circuitry 128.

5 In some embodiments, FFT circuitry 122a-d may comprise first FFT circuitry 122a to perform an FFT on parallel groups of time domain samples of a first subchannel from the first antenna to generate frequency domain symbol-modulated subcarriers of the first subchannel from the first antenna. FFT circuitry 122a-d may also include second FFT circuitry 122b to perform an FFT on parallel groups of time domain samples of a second subchannel from the first antenna to generate frequency domain symbol-modulated subcarriers of the
10 second subchannel from the first antenna. FFT circuitry 122a-d may also include third FFT circuitry 122c to perform an FFT on parallel groups of time domain samples of the first subchannel from the second antenna to generate frequency domain symbol-modulated subcarriers of the first subchannel from the second antenna. FFT circuitry 122a-d may also include fourth FFT circuitry 122d to
15 perform an FFT on parallel groups of time domain samples of the second subchannel from the second antenna to generate frequency domain symbol-modulated subcarriers of the second subchannel from the second antenna. In some embodiments, the OFDM symbol may be generated from the simultaneous receipt and processing of two subchannels through two antennas, although the
20 scope of the invention is not limited in this respect.

In referring to FIGs. 2A & 2B, receiver configuration 200 may receive more than one subchannel of a wideband OFDM channel through a single antenna selected from a plurality of spatially diverse antennas 202a-d. In some embodiments, receiver configuration 200 may comprise a single channel pipeline
25 (SCP) for processing each subchannel.

Receiver configuration 200 may comprise antenna selection circuitry 204 to select one of a plurality of spatially diverse antennas 202a-d to receive an orthogonal frequency division multiplexed symbol over a wideband channel comprising more than one of a plurality of subchannels. LNA 206 may amplify
30 the RF signals, and each subchannel may be separately downconverted by downconverters 208a-d, filtered by filters 212a-d, and converted to digital signals 215 by analog-to-digital conversion circuitry 214a-d. Digital signal processing circuitry 216 may comprise, among other things, subcarrier

demodulators to demodulate frequency domain symbol-modulated subcarriers of the more than one subchannel to generate parallel groups of bits from the subcarriers. Digital signal processing circuitry 116 may also comprise additional processing circuitry to generate single decoded bit stream 229 representing the
5 orthogonal frequency division multiplexed symbol from the more than one subchannel. In some embodiments, heterodyne frequency generating circuitry 210 may selectively generate a heterodyne frequency for each subchannel to convert RF signals of the particular subchannel to baseband.

As illustrated in FIG. 2B, digital signal processing circuitry 216 may
10 receive digital signals 215 from portion 218 and may comprise four single channel pipelines (SCPs). In these embodiments, each single channel pipeline may process one subchannel, although the scope of the invention is not limited in this respect.

In some embodiments, receiver configuration 200 may also include
15 circuitry 220a-d to remove a cyclic extension and/or guard interval (GI) from the serial symbol streams provided by analog-to-digital conversion circuitry 214a-d, although the scope of the present invention is not limited in this respect. The serial symbol streams may be converted to a parallel form for processing by fast Fourier transform circuitry 222a-d. Fast Fourier transform circuitry 222a-d may
20 perform a fast Fourier transform on the parallel groups of time-domain samples to generate frequency domain symbol-modulated subcarriers. Equalizer circuitry 226a-d may receive the symbol-modulated subcarriers, in parallel for each subcarrier, and it may perform an equalization based on the channel estimates. After equalization, the frequency domain symbol-modulated subcarriers may be
25 demapped, and a parallel-to-serial conversion may be performed prior to deinterleaving and/or decoding by circuitry 228 to generate decoded bit stream 229. In some embodiments, the demodulated OFDM symbol may be generated from the simultaneous receipt and processing of four subchannels through one antenna, although the scope of the invention is not limited in this respect.

30 In referring to FIGs. 3A & 3B, receiver configuration 300 may receive a single subchannel by a plurality of spatially diverse antennas 302a-d, and maximum-ratio combining may be performed on corresponding symbol-modulated subcarriers received by the antennas. In some embodiments, receiver

configuration 300 may comprise circuitry 318 to receive an orthogonal frequency division multiplexed symbol over a single subchannel through a plurality of spatially diverse antennas, and combining circuitry 324 to combine corresponding frequency domain symbol-modulated subcarriers from each of the
5 antennas to generate combined symbol-modulated subcarriers for the single subchannel. LNAs 306a-d may amplify the received RF signals, and the RF signals from each antenna 302 may be separately downconverted by downconverters 308a-d, filtered by filters 312a-d, and converted to digital signals 315 by analog-to-digital conversion circuitry 314 314a-d. Since a single
10 subchannel is being received, the signals from each antenna may use the same heterodyne frequency for downconversion, and accordingly VCO 310 may generate a single heterodyne frequency for each downconversion circuitry 308a-d to downconvert the RF signals from each antenna to baseband.

In some embodiments, receiver configuration 300 may comprise a single
15 channel pipeline (SCP) for each antenna for the signals of the same subchannel. As illustrated in FIG. 3B, digital signal processing circuitry 316 may comprise four single channel pipelines. Each pipeline may process signals from one antenna, although the scope of the invention is not limited in this respect.

In some embodiments, receiver configuration 300 may also include
20 circuitry 320a-d to remove a cyclic extension and/or guard interval (GI) from the serial symbol streams provided by analog-to-digital conversion circuitry 314a-d, although the scope of the present invention is not limited in this respect. The serial symbol streams may be converted to a parallel form for FFT circuitry 322a-d. FFT circuitry 322a-d may perform a fast Fourier transform on the
25 parallel groups of time-domain samples to generate frequency domain symbol-modulated subcarriers. Equalizer circuitry 326 may receive the symbol-modulated subcarriers, in a parallel form for each subcarrier, and it may perform an equalization based on the channel estimates. After equalization, the frequency domain symbol-modulated subcarriers may be demapped, and a parallel-to-serial
30 conversion may be performed prior to deinterleaving and/or decoding by circuitry 328 to generate decoded bit stream 329. In some embodiments, the OFDM symbol may be demodulated from the simultaneous receipt and

processing of one subchannel through four antennas, although the scope of the invention is not limited in this respect.

In some embodiments, combining circuitry 324 comprises maximum-ratio combining (MRC) circuitry having complex (i.e., I and Q) weighters 330a-d
5 to weight the frequency domain symbol-modulated subcarriers prior to proportionally combining the corresponding frequency domain symbol-modulated subcarriers substantially proportional to their signal strength in combiners 332. In these embodiments, weighters 330a-d may, in addition to weighting, correct, adjust and/or phase-rotate a frequency domain symbol-
10 modulated subcarrier to allow coherent signal combining in combiners 332. In some embodiments, receiver configuration 300 may include one of combiners 332 for each subcarrier.

Although the receiver configurations 100 (FIGs. 1A & 1B), 200 (FIGs. 2A & 2B) and 300 (FIGs. 3A & 3B) are illustrated as having several separate
15 functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements, such as processing elements including digital signal processors (DSPs), and/or other hardware elements. For example, processing elements may comprise one or more microprocessors, DSPs, application specific integrated circuits (ASICs), and
20 combinations of various hardware and logic circuitry for performing at least the functions described herein.

Antennas 102a-d (FIGs. 1A & 1B), 202a-d (FIGs. 2A & 2B) and 302a-d (FIGs. 3A & 3B) may comprise directional or omnidirectional antennas, including, for example, dipole antennas, monopole antennas, loop antennas,
25 microstrip antennas or other types of antennas suitable for reception of RF signals by the receivers.

In some embodiments, a reconfigurable receiver is provided. The reconfigurable receiver may comprise antenna selection circuitry to select one or more of a plurality of spatially diverse antennas to receive one or more of a
30 plurality of subchannels. The reconfigurable receiver may also comprise maximum-ratio combining circuitry to combine, when more than one antenna per subchannel is selected, corresponding symbol-modulated subcarrier of subchannels from different selected antennas. In some embodiments, the antenna

selection circuitry may select at least one antenna of the plurality to receive either three or four subchannels when a high-throughput mode is enabled. In some embodiments, the antenna selection circuitry may select up to four of the antennas to receive a single subchannel when an increased-range mode is enabled. In some embodiments, the antenna selection circuitry may select at least two of the antennas to simultaneously receive two of the subchannels when the increased-range and the high-throughput modes are enabled. The antenna selection circuitry may select the antennas based on an average signal-to-noise ratio of the subchannels, although the scope of the invention is not limited in this respect.

In some embodiments, the reconfigurable receiver may comprise up to four or more single channel pipelines to process signals. In some embodiments, when the high-throughput mode is enabled, each single channel pipeline may process signals from an associated one of the either three or four subchannels. In some embodiments, when the increased-range mode is enabled, each single channel pipeline may process signals of the single subchannel received by an associated one of the selected antennas. In some embodiments, when the increased-range and the high-throughput modes are both enabled, a first single channel pipeline may process signals of a first subchannel received by a first of the selected antennas, a second single channel pipeline may process signals of a second subchannel received by the first antenna, a third single channel pipeline may process signals of the first subchannel received by a second of the selected antennas, and a fourth single channel pipeline may process signals of the second subchannel received by the second of the selected antennas.

FIG. 4 is a flow chart of an OFDM signal reception procedure in accordance with some embodiments of the present invention. The operations of procedure 400 may be performed by an OFDM receiver, such as a receiver in accordance with receiver configuration 100 (FIGs. 1A & 1B), receiver configuration 200 (FIGs. 2A & 2B), and/or receiver configuration 300 (FIGs. 3A & 3B), although other receivers may also be suitable to perform the operations of procedure 400. In general, procedure 400 may receive OFDM communications over one or more subchannels through one or more antennas, and it may selectively trade off between throughput and range in a WLAN environment.

Although the individual operations of procedure 400 are illustrated and described as separate operations, one or more of the individual operations may be performed concurrently, and nothing requires that the operations be performed in the order illustrated.

5 Operation 402 may select among one or more antennas to receive one or more subchannels. In some embodiments, operation 402 may select one antenna to receive up to four or more subchannels, which may provide increased throughput with a more limited range. In other embodiments, operation 402 may select up to four or more antennas to receive a single subchannel, which may
10 provide an increased range with reduced throughput. In yet other embodiments, operation 402 may select more than one antenna to receive more than one subchannel to provide an increased throughput and an increased range. For example, operation 402 may select two antennas to each receive two subchannels each, although the scope of the invention is not limited in this respect.

15 Operation 404 may process signals in single-channel pipelines. For example, when a single antenna is used to receive up to four or more subchannels, each subchannel may be processed in a single-channel pipeline. For example, when more than one antenna is used to receive a single subchannel, the same subchannel-signals from each antenna may be processed in a single-
20 channel pipeline. For example, when more than one antenna is used to each receive more than one subchannel, each subchannel may be processed in a corresponding single-channel pipeline. The single-channel pipeline may include, among other things, downconversion, analog-to-digital conversion, and performing FFTs to generate frequency domain symbol modulated subcarriers.

25 Operation 406 may combine outputs of the single-channel pipelines that represent the same subchannel. For example, operation 406 may combine corresponding frequency domain symbol modulated subcarriers of the same subchannel when more than one antenna is used to receive the same subchannel. In some embodiments, operation 406 may perform a maximum-ratio combining
30 on the corresponding frequency domain symbol modulated subcarriers, although the scope of the invention is not limited in this respect. Operation 406 may optionally not be performed in some embodiments when a single antenna is used to receive one or more subchannels, or when the single-channel pipelines are

used to receive different subchannels. Operation 406 may provide combined frequency domain symbol modulated subcarriers for each subchannel that is received.

5 Operation 408 may perform a channel equalization on the combined frequency domain symbol modulated subcarriers for each subchannel in embodiments that receive more than one subchannel. The subcarriers may be demodulated, and parallel groups of bits may be generated. Each parallel group may correspond to a subcarrier of a subchannel.

10 Operation 410 may receive parallel groups of bits for each subchannel for each subchannel and may determine an OFDM symbol from the bits for each subchannel. Operation 410 may include converting the parallel groups of bits for each subchannel to a serial form that may comprise one or more serial bit streams. Operation 410 may also include performing demapping, deinterleaving and/or decoding.

15 In some embodiments, the selection between increased range and increased throughput may be performed by a user of a wireless communication device. In other embodiments, the selection between increased range and increased throughput may be made by an application operating on the device. In these embodiments, the selection may be based on the requirements of the
20 application and/or channel conditions. For example, for voice communications, greater range and lower throughput may be acceptable, while for data transfer, higher throughput may be desired.

 Embodiments of the invention may be implemented in one or a combination of hardware, firmware and software. Embodiments of the invention
25 may also be implemented as instructions stored on a machine-readable medium, which may be read and executed by at least one processor to perform the operations described herein. A machine-readable medium may include any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computer). For example, a machine-readable medium may
30 include read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, electrical, optical, acoustical or other form of propagated signals (e.g., carrier waves, infrared signals, digital signals, etc.), and others.

The Abstract is provided to comply with 37 C.F.R. Section 1.72(b) requiring an abstract that will allow the reader to ascertain the nature and gist of the technical disclosure. It is submitted with the understanding that it will not be used to limit or interpret the scope or meaning of the claims.

5 In the foregoing detailed description, various features are occasionally grouped together in a single embodiment for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments of the subject matter require more features than are expressly recited in each claim. Rather, as the following claims
10 reflect, invention lies in less than all features of a single disclosed embodiment. Thus the following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate preferred embodiment.